BELLCOMM, INC.

SUBJECT: Relative Lift-off Conditions of Titan III-C and Saturn V, and the Effects of Programmed Attitude Control - Case 320

DATE: November 17, 1967

FROM: J. A. Llewellyn

ABSTRACT

Early lift-off drift and tower impact studies which had been conducted for Titan III-C and Saturn V were analyzed. For Titan III-C, programmed biasing was considered, but program management decided in favor of a 50% placard of the conservative Titan III-C specification wind to eliminate any possible collision problem.

Yaw biasing was selected for Saturn V as a means of eliminating launch day surface wind restrictions for all flights, particularly those flights with low thrust-to-weight ratios at lift-off, and minimizing LUT damage due to engine hot gas impingement.

(NASA-CR-93037) RELATIVE LIFT-OFF CONDITIONS OF TITAN 3-C AND SATURN 5, AND THE EFFECTS OF PROGRAMMED ATTITUDE CONTROL (Bellcomm, Inc.) 16 p

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MEMORANDUM FOR FILE

INTRODUCTION

Reference 1 requests an analysis of the relative lift-off conditions of Titan III and Saturn V, and the effects of programmed attitude control from the pad. Data utilized for this analysis have been obtained from the listed references, discussions with MSFC personnel, and discussions with Titan III personnel at Martin-Denver. The two airborne/ground configurations are significantly different; however, as will be shown, the problems of potential collision with ground equipment immediately after lift-off were quite similar. The solutions to the problems were different, as the discussion will show.

SATURN V

The pad orientation of the Saturn V vehicle with respect to the LUT (Launch Umbilical Tower) is shown in Figure 1. As can be seen, a 180° wind (south to north wind) could force the vehicle in the direction of the LUT, and this constitutes the basis for concern. Summarized in Reference 2, dated November 9, 1966, are the results of the original six-degree-of-freedom, rigid-body dynamics analysis of the space vehicle's trajectory from lift-off until the S-IC engine nozzles clear the top of the LUT. The effects of distributed nonlinear aerodynamics, first order actuators, the soft release mechanism, and 3σ vehicle uncertainties were all considered to give the zero wind lift-off trajectory. It was then calculated that a wind amplitude of 7.8 M/SEC would be the limiting value for tower clearance, as shown on Figure 2. This converts to a launch wind constraint to exclude a launch in any wind with a southerly component greater than 7.8 M/SEC. Such a wind constraint is shown in Figure 3 along with various percentile winds for February and March.

The original analysis was updated by Reference 3, dated July 21, 1967, using increased control system gains, AS-501 measured center engine misalignment, and a programmed yaw bias. The gains had been increased for better control system stability margins and to improve survival in the event of certain malfunction conditions; however, the change also reduced the space vehicle's lift-off dispersions. The measured center engine cant of .91° just happens to be in the direction to steer the vehicle away from the LUT. Of course, the yaw bias program, shown in Figure 4 as a function of flight time, was selected to increase tower clearance.

The results of the Reference 3 analysis can be seen from Figure 5; adequate LUT clearance is assured even with a 95 percentile, 180° wind. Figure 6 shows that significant margins exist even with a 99 percentile wind; the wind constraint is effectively removed from the vehicle/tower impact problem. Table 1 summarizes all lift-off clearances, and shows the effects of yaw biasing and the revised control system. The table also shows that there are other possible interference points during lift-off.

Yaw biasing was perhaps not required for AS-501--as shown by the last entry in Table 1. On subsequent Saturn V flights, however, where the effects of wind are more pronounced due to lower lift-off thrust to weight ratios (T/W = 1.24 for AS-501; 1.18 for AS-504) and center engine misalignment may not be favorable, the yaw biasing will probably be required. An additional benefit of yaw biasing is to help minimize LUT damage from engine hot gas impingement.

TITAN III

Analyses performed for Titan III-C, Reference 4, indicate that the specification winds could force the vehicle into the oscillation envelope of the retracted umbilical mast, as shown in Figure 7. Included in Martin-Denver's drift study were eight "random independent variables", such as thrust vector misalignment, and center of gravity offset; also included were factors such as Inertial Guidance System (IGS) error and the thrust/weight ratio of 1.67.

One solution to the vehicle/mast impingement problem considered was a pitch steering program. The IGS issues discrete steps of attitude commands of approximately 0.18° per step. Figure 8 shows that a three-step command would provide the necessary clearance.

An alternate solution would be a wind placard. The 624A specification wind is 40 knots at 15 feet elevation with the following altitude variation:

$$v = 40 \left(\frac{h}{15}\right)^{.2}$$

This is actually a very conservative (high) specification. Since the wind drift was added to other trajectory dispersions, it accounts for 67 inches of the 92 inch drift. A wind placard of 50% of 624A specification winds gives only 25 inches of drift, leaving 42 inches of clearance. This was the solution selected by the Air Force.

CRITICAL GROUND WIND PROBABILITY

Table 2 is presented to give the reader a better appreciation of the probability of actually encountering ground winds of the magnitude and direction necessary to cause a collision in the cases discussed above. That is, it allows the reader to evaluate the severity of the launch constraint.

SUMMARY

In the case of Titan III-C, a 50% placard of a conservative wind was used to eliminate any possible collision problem. The probability of exceeding the 50% wind at ETR, even in the windiest month, is rather small (3%). Martin-Denver reports that winds have not approached the limit levels during the launches to date. It is interesting to note that Gemini Launch Vehicle tower clearance studies, References 5 and 6, showed no collision problems with 99 percentile surface winds, even with actuator off-null errors of .7°. (The specification limit was .25°.)

Saturn V, AS-501 studies, when latest center engine misalignment and control system data were used, indicate the yaw biasing was not actually required. However, when considering later vehicles with lower T/W at lift-off, and considering that yaw biasing tends to minimize LUT blast damage, the biasing appears to be justifiable.

2031-JAL-mch

J. A. Llewellyn

Attachments

REFERENCES

1. Informal note from Dr. George Mueller to Gen. S. C. Phillips, dated October 9, 1967.

2. "Saturn V Launch Vehicle Flight Dynamics Analysis, SA-501" D5-15509-1, The Boeing Company, dated November 9, 1966.

3. "Saturn V Launch Vehicle Flight Dynamics Analysis, SA-501" D5-15509-1B, The Boeing Company, dated July 21, 1967.

4. Letter from J. U. La France, Martin-Marietta Corporation to J. A. Llewellyn, dated November 2, 1967.

5. "GLV Launch Stand Clearance", LV 319, Martin-Marietta Corporation, dated December, 1963.

6. "Gemini Program Launch Systems Final Report" Aerospace Corporation, dated January, 1967.

7. "AS-501 Mission Constraints" - Meeting Handout by Roger Teague, MSFC, dated May 17, 1967

TABLE 1 (FROM REF. 3)

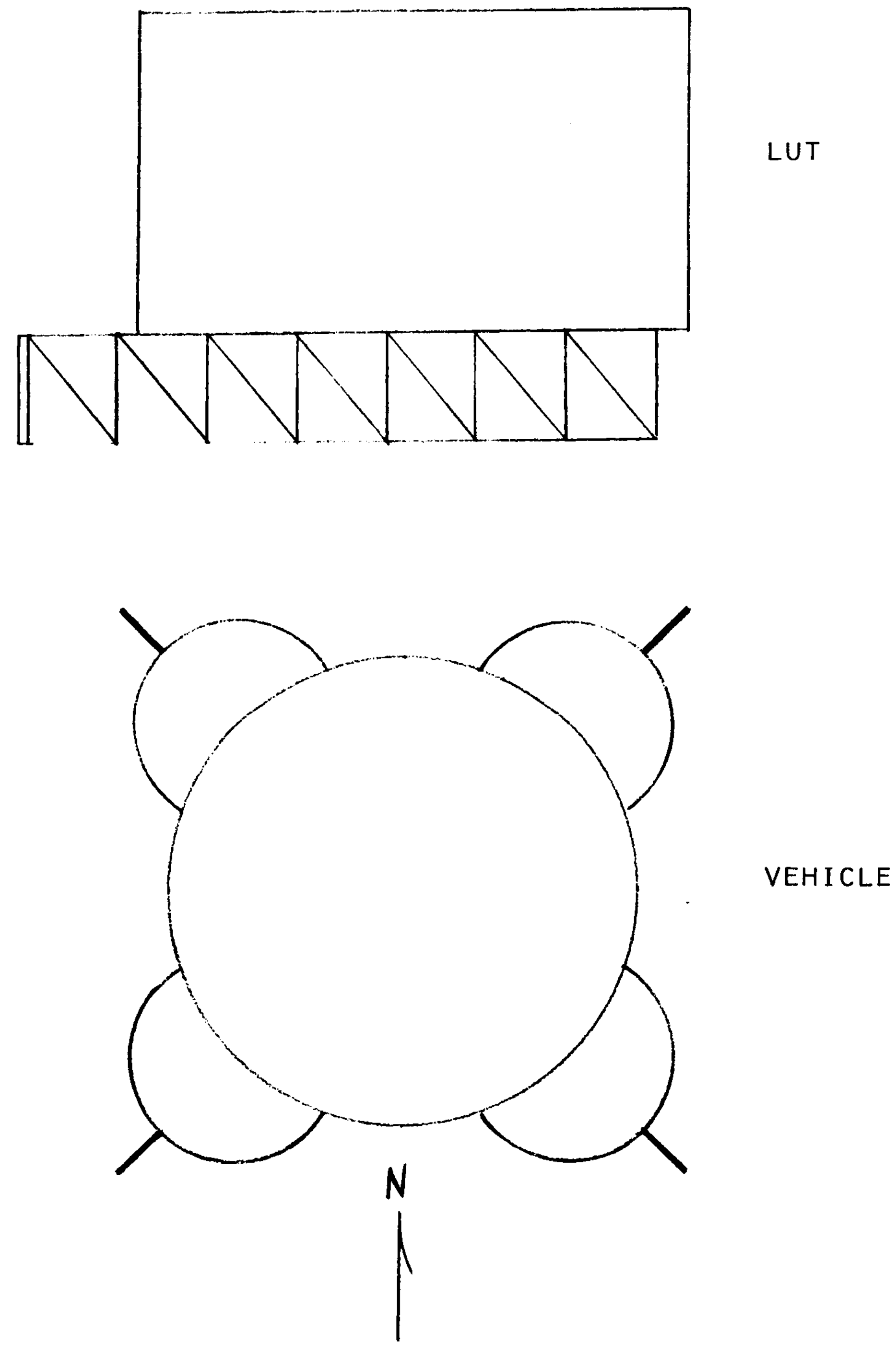
SUMMARY OF LIFTOFF CLEARANCES

POTENTIAL INTERFERENCE		AVAILABLE CLEARANCE	SA-501	EFFECT OF YAW BIAS AND REVISED CONTROL SYSTEM	
VEHICLE	GROUND EQUIPMENT		MINIMUM CLEARANCE	MINIMUM CLEARANCE W/O YAW BIAS REV CONTROL SYSTEM	MINIMUM CLEARANCE WITH YAW BIAS CONTROL SYSTEM REF 49
		METERS	METERS	METERS	METERS
Thrust Structure	Holddown Post	.0775	.0254	.0254	.0356
Airscoops	Holddown Post	.104	.0175	.0175	.0204
Thrust Structure Insulation	Liftoff Switches	Variable	.0126	.0126	.0305
Airscoops	Tail Service Mast	Variable	.394	.394	.457
Engine Bell	Holddown Post	.713	.386	.432	.468
Service Module	SM Swing Arm	Variable	1.04	.965	.519
S-IVB Stage	S-IVB Forward Swing Arm	Variable	1.04	1.02	.610
S-II/S-IVB Inter-stage	S-IVB Aft Swing Arm	Variable	.305	.178	.127
S-II Stage	S-IIForward Swing Arm	Variable	1.17	1.17	1.02
S-II Stage	S-II Intermediate Swing Arm	Variable	1.17	1.17	1.02
S-IC Fin Tip	Service Module Swing Arm	8.4	7.4	4.4	5.9

TABLE 2

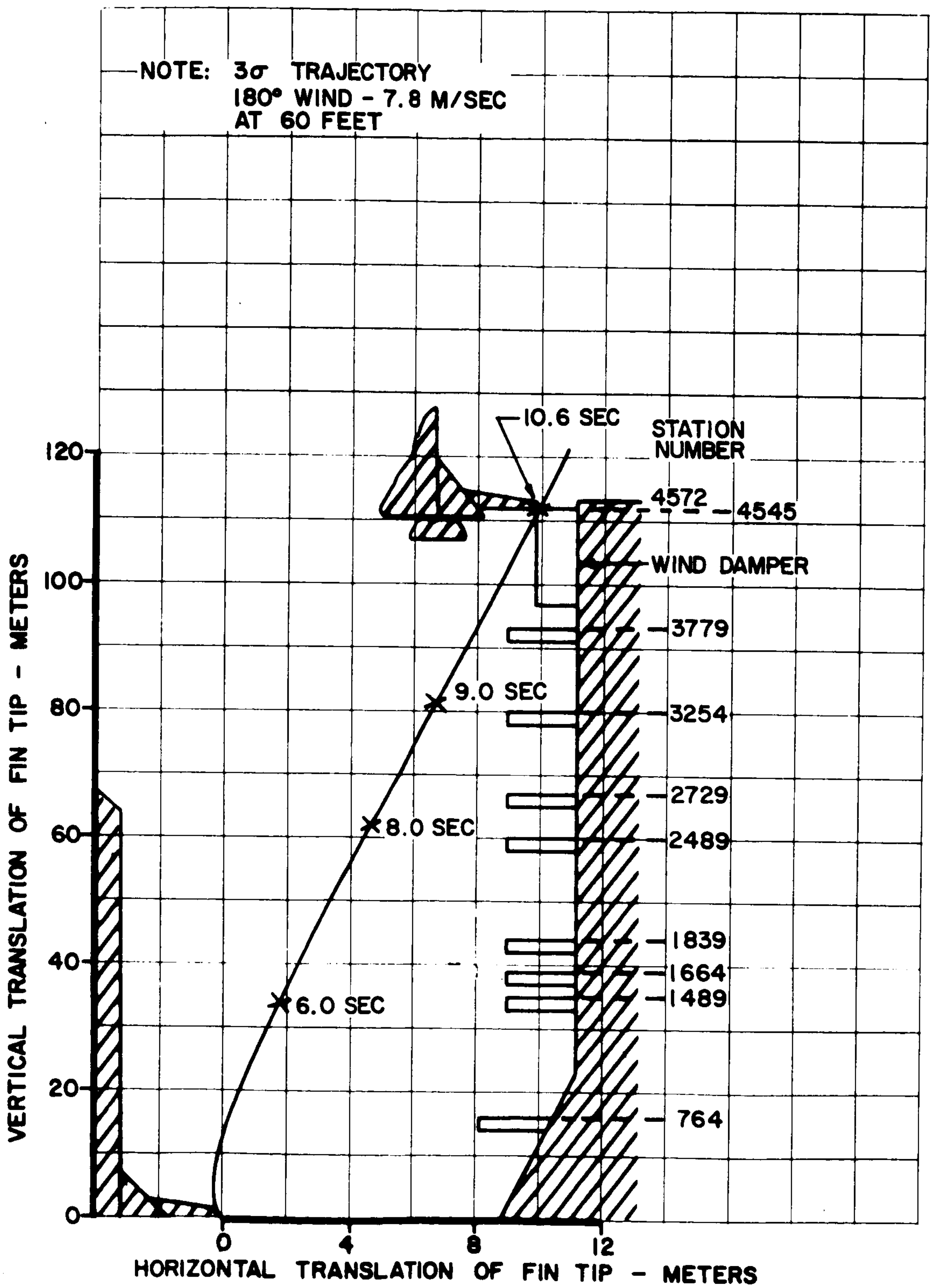
CASE	CRITICAL SURFACE WIND	PROBABILITY OF EXCEEDING CRITICAL WIND*
SATURN V AS-501, ORIGINAL ANALYSIS	7.2 M/S AT 180° AZIMUTH	5%
SATURN V AS-501, WITH MEASURED ENGINE CANT, YAW BIAS AND INCREASED CONTROL GAINS.	17.2 M/S AT 160° AZIMUTH	.2%
TITAN III-C, WITH NO PLACARD	20.6 M/S AT 100° AZIMUTH	.2%
TITAN III-C, WITH 50% PLACARD	10.3 M/S AT 100° AZIMUTH	3%

*BASED ON WINDIEST MONTH CONCEPTS.



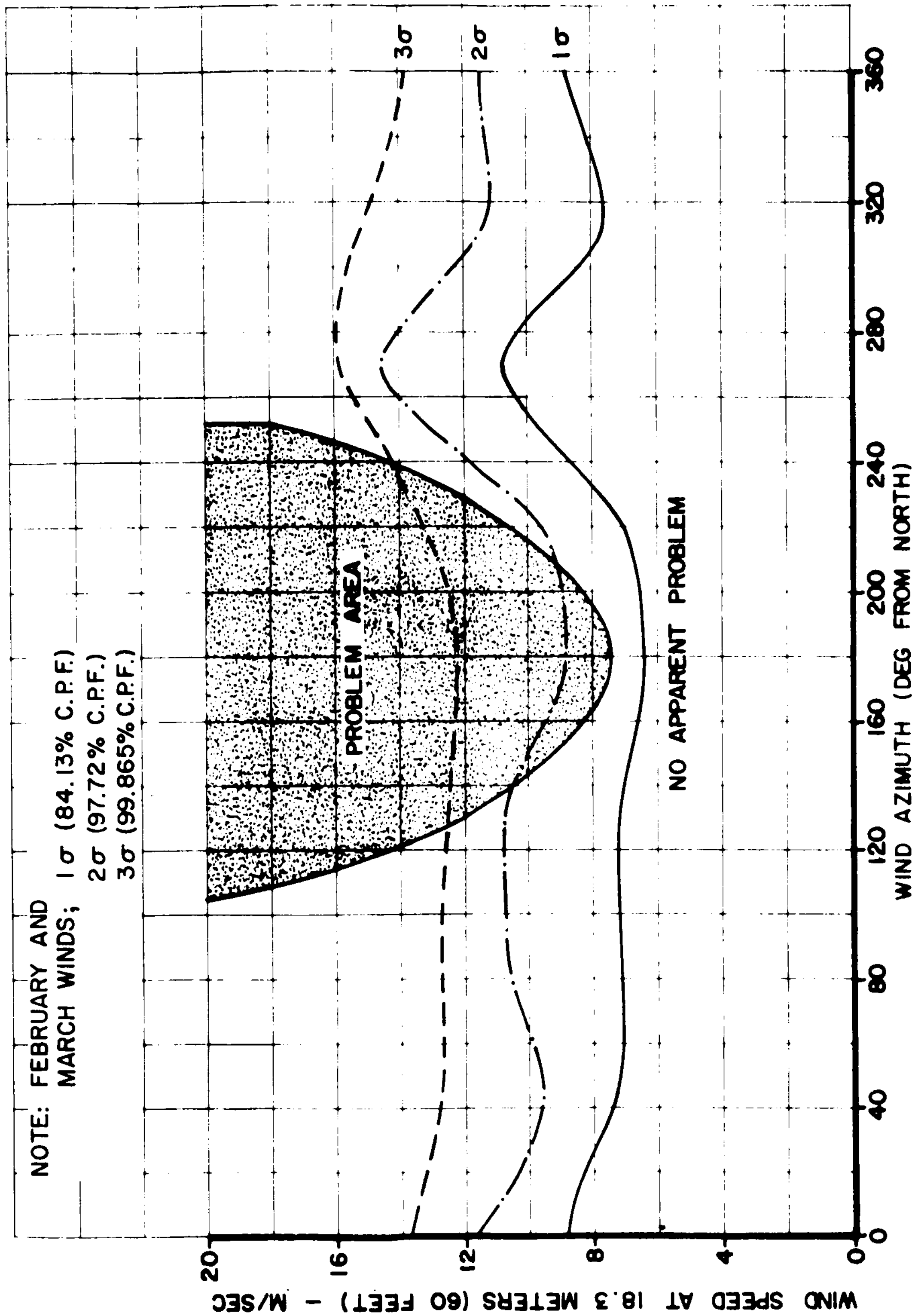
SATURN V LIFT-OFF GEOMETRY

FIGURE 1



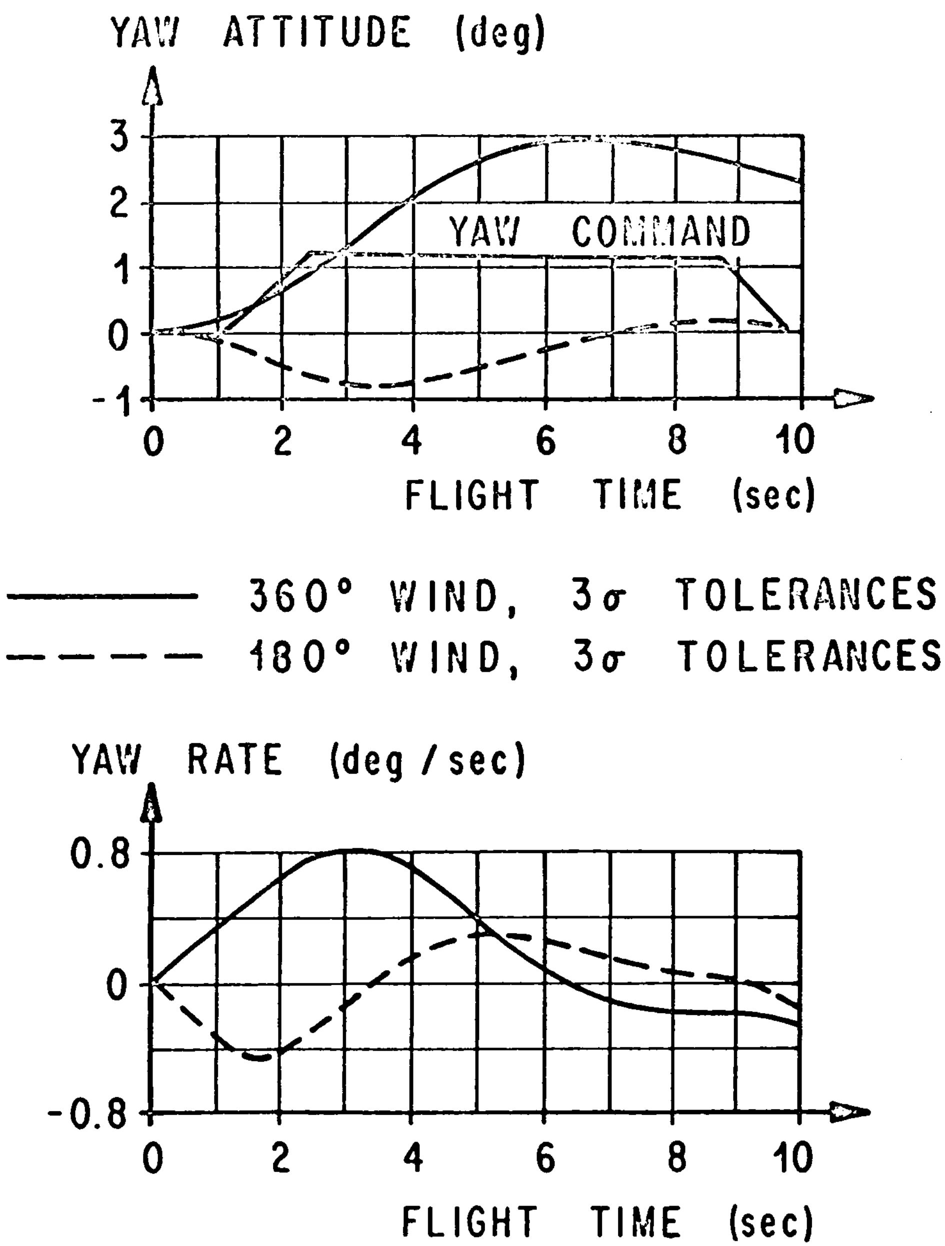
NEAR PAD TRAJECTORY FOR 180° WIND SPEED LIMIT

FIGURE 2 (FROM REF. 2)



STEADY STATE WIND SPEED LIMIT FOR TOWER CLEARANCE

FIGURE 3 (FROM REF. 2)



SATURN V

LIFTOFF

DYNAMICS

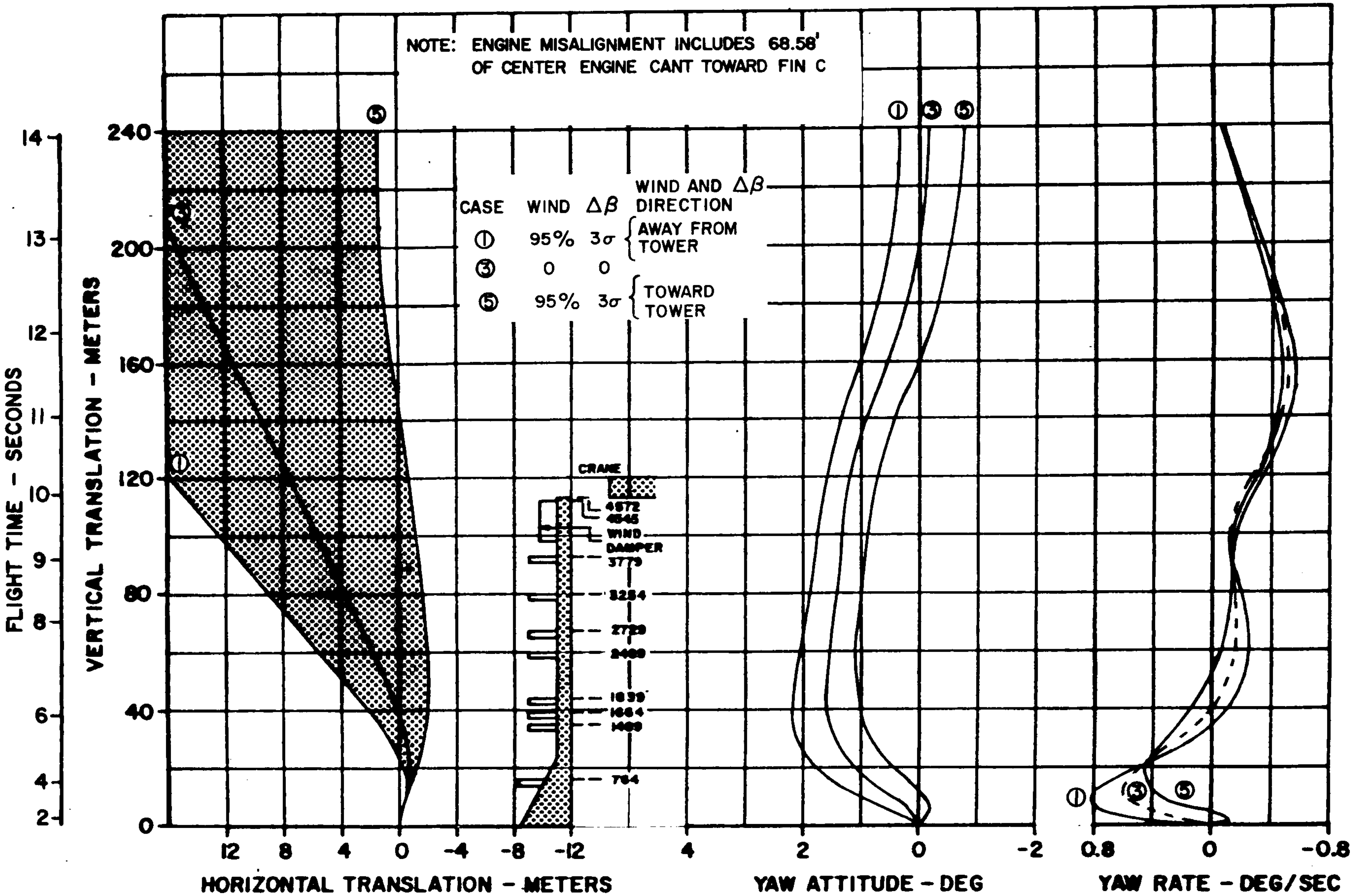
AS-501

YAW

BIAS

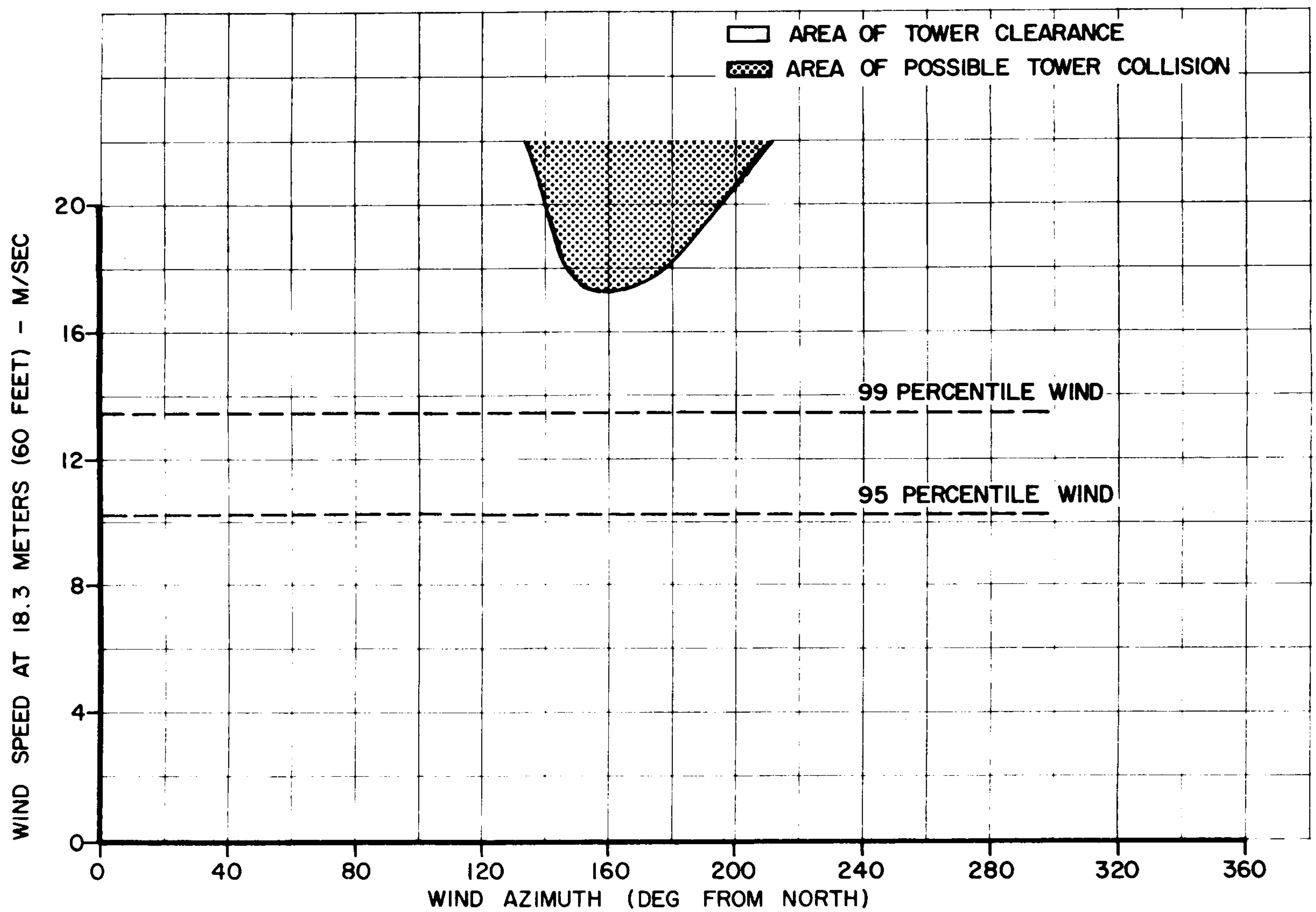
R-AERO-P, ROGER TEAGUE (876-4443), MAY 17, 1967

FIGURE 4 (FROM REF. 7)



LIFTOFF ENVELOPES OF FIN TIP "A"

FIGURE 5 (FROM REF. 3)



STEADY STATE GROUND WIND SPEED LIMIT

FIGURE 6 (FROM REF. 3)

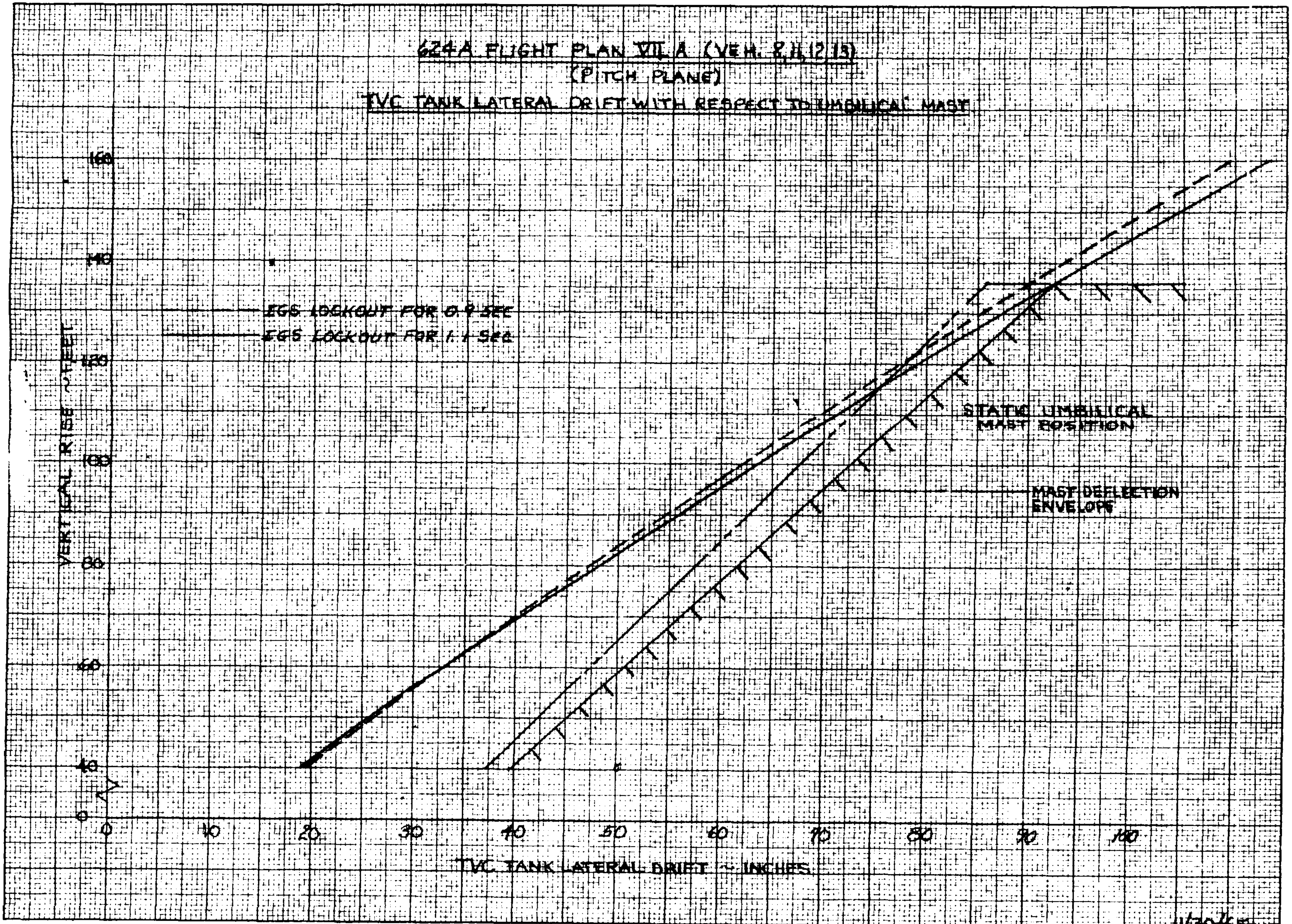


FIGURE 7 (FROM REF. 4)

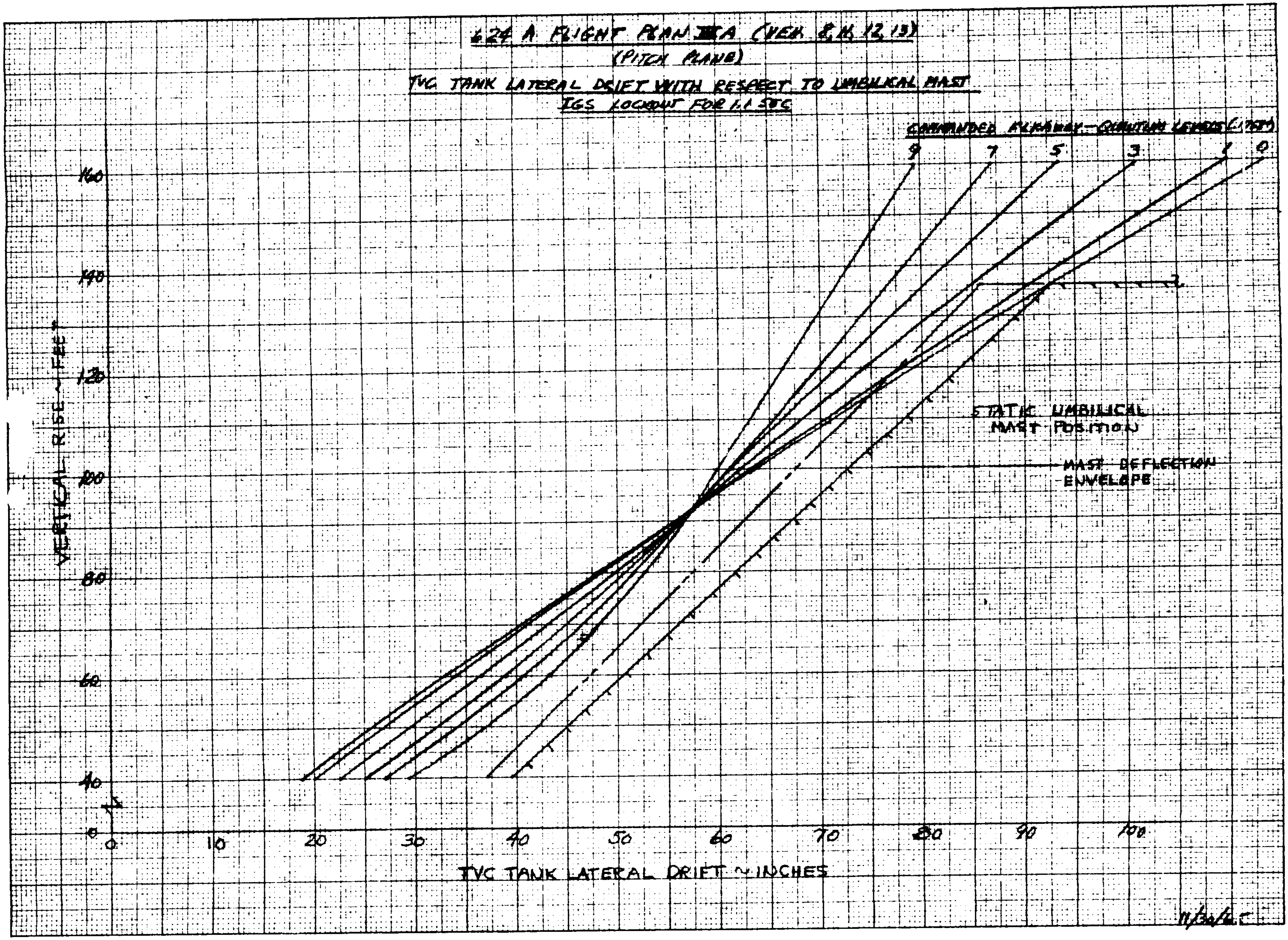


FIGURE 8 (FROM REF. 4)

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